Dependence of the Single-Scattering Properties of Small Ice Crystals on Idealized Shape Models

Research Highlight

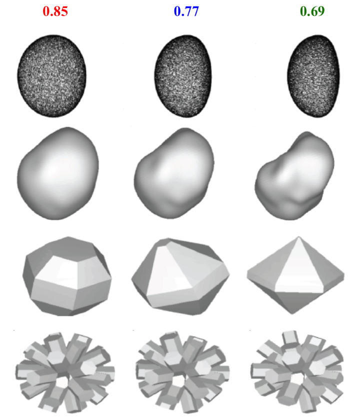
Images of ice crystals from cloud probes installed on aircraft flying through ice clouds during the Tropical Warm Pool-International Cloud Experiment (TWP-ICE) and other field campaigns in diverse geographic regimes have shown that small ice crystals appear quasi-circular. Because of this, the idealized models that have previously been developed to represent the shapes of small ice crystals, such as Chebyshev particles, Gaussian random spheres, and droxtals, are all quasi-spherical in shape. However, state-of-the-art cloud probes (e.g., Cloud Particle Imager (CPI)) have insufficient resolution and diffraction effects that make it difficult to distinguish the fine structures of small ice crystals, and hence, it has not been possible to determine which of the previously used crystal models best represents the imaged crystals.

Past laboratory studies have shown that ice crystals grown in a fall tower were faceted or had emerging arms at sizes of 5–10 micrometers. Some of the ice crystals larger than 10 micrometers were also faceted and had budding arms when imaged by the Desert Research Institute (DRI) high-resolution cloud scope. Another laboratory study showed that an ice analogue grown from sodium fluorosilicate solution on a glass substrate had a similar crystalline structure to real ice crystals and appeared quasi-circular when imaged by a CPI. This ice analogue had a complex structure of several columns originating from a common center of mass, similar to the small ice crystals observed in the DRI fall tower. Thus, there is a significant discrepancy between the shapes of the previously used shape models (i.e., Chebyshev particle, Gaussian random sphere, and droxtal) and the shapes of the ice analogue and the small ice crystals grown in the fall tower, even though all look similar when imaged by state-of-the-art cloud probes such as a CPI. Therefore, a new idealized model called a budding Bucky ball (3B) that resembles the small ice analogue and small ice crystals in the fall tower has been developed.

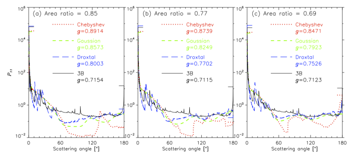
The single-scattering properties (scattering phase function P11 and asymmetry parameter g) of different idealized models representing shapes of small ice crystals were computed by a ray-tracing code at an incident wavelength of 0.55 micrometers. Because variations in scattering properties can be dominated by differences in particle cross-sectional areas, the models of the small ice crystals were generated so that the cross-sectional area was the same for all the different idealized models. For each method, three different ice crystal models with area ratios of 0.85, 0.77, and 0.69 were generated, where area ratio is defined as the average cross-sectional area of the particle divided by that of circumscribed circle with diameter given by the crystal maximum dimension, D=50 micrometers.

Compared with previously used models, the 3B scatters less light in the forward direction and more light in the lateral and backward directions. The Chebyshev particles and Gaussian random spheres show smooth and featureless P11, whereas droxtals and 3Bs, which have a faceted structure, show several peaks in P11 associated with angles of minimum deviation. Overall, the difference in the forward (lateral; backward) scattering between models is up to 22% (994%; 132%), 20% (510%; 101%), and 16% (146%; 156%) for small ice crystals with respective area ratios of 0.85, 0.77, and 0.69. The g for different models varies by up to 25%, 23%, and 19% for particles with area ratios of 0.85, 0.77, and 0.69, respectively.

The single-scattering properties of small ice crystals depend heavily on the choice of idealized model and area ratio. Because current state-of-the-art cloud probes cannot distinguish between these different models for small crystal shapes, all should be regarded as equally plausible representations of small ice crystals. This study quantifies the uncertainties in the single-scattering properties of small ice crystals



Chebyshev particles (first row), Gaussian random spheres (second row), droxtals (third row), and budding Bucky ball (fourth row) with varying area ratios of 0.85 (left column), 0.77 (middle column), and 0.69 (right column).



Scattering phase function and asymmetry parameter for Chebyshev particles, Gaussian random spheres, droxtals, and budding Bucky ball (3B) with varying area ratio of 0.85 (a), 0.77 (b), and 0.69 (c).

at solar wavelengths. Different cloud probes or direct observations of the scattering phase functions of distributions of ice crystals are needed to differentiate which model best represents small ice crystals. Studies on the growth mechanisms for small ice crystals are also needed to understand how their shapes depend on atmospheric parameters (e.g., temperature, pressure, and humidity) and on formation mechanisms (heterogeneous versus homogeneous freezing), and how they evolve with time. A subsequent study will also examine how the choice of small crystal models and area ratio affects contributions of small ice crystals on the bulk scattering properties of observed distributions of ice crystals with varying shapes and sizes.

Reference(s)

Um J and GM McFarquhar. 2011. "Dependence of the single-scattering properties of small ice crystals on idealized shape models." Atmospheric Chemistry and Physics, 11, doi:10.5194/acp-11-1-2011.

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